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WELDABILITY OF HEAT-RESISTANT MATERIAL SAP BY METHOD OF FUSION

[Following is a translation of an article by Cand. Tech. Sciences, G. D. Nikiforov, and Engr., S. N. Zhiznyakov in the Russian-language journal Svarochnoye Proizvodstvo (Welding Production), Moscow, No 6, June 1964, pp 1-4.]

Technology was developed for manufacture of SAP, possessing the ability to be welded by the method of fusion, and also technology of its argon-arc welding.

Of all existing aluminum alloys, sufficient strength at a temperature of 350 -- 500° C can be preserved only by material from sintered aluminum powder (SAP), the strengthening phase in which is oxide of aluminum. Basic initial product for obtaining SAP is finely-dispersed aluminum powder which is obtained by atomization of liquid aluminum with compressed air, with subsequent crushing in ball mills in an oxidizing atmosphere.

The process of production of SAP consists of the following basic operations: briquetting of finely-dispersed powder under a specific pressure of 35 -- 50 kg/mm^2; prepressing of briquettes at a temperature of 450 -- 500° C and pressure of 40 -- 60 kg/mm^2; pressing of half-finished products at a temperature of 450 -- 500° C.

In the process of briquetting, prepressing and pressing of blanks, there occours a partial destruction of oxidized films of aluminum, as a result of which there appear metallic bands between separate particles of powder. As a result, there are

created conditions for obtaining high-strength properties at low and, what is most important, at high temperatures, inasmuch as at high temperatures dispersed oxides of aluminum do not coagulate and are not dissolved, preserving their position, at which they wedge the planes of slip and block the boundary of grains, preventing diffusion flow of material.

From SAP it is possible to prepare sheets, rods, pipes, all possible profiles, stamping and so forth.

Besides high strength at normal and high temperatures, SAP possesses high corrosion stability, ability to preserve its properties after annealing at temperatures of 450 -- 500° C and small effective absorption cross section of neutrons.

A serious deficiency of SAP, delaying its wide application in industry, is the impossibility of welding it by the method of fusion [1, 2].

Experiments performed by us on argon-arc welding of sheets of SAP-1 material showed that welding by fusion is impossible in connection with poor stability of arc and difficulty of formation of melting pool due to ejection of liquid basic and welding metals in the form of porous drops and incrustations on edges of welded plates (Figure 1).

At the same time, it was found in a number of cases that on separate small sections, the welded joint can form as a result of partial dissolution of SAP in a puddle of liquid metal. In connection with this, it was resolved to search for a method of artificial creation of liquid melting pool of significant volume and, as a result of its contact with edges of welded plates, to achieve their dissolution and to obtain the thus welded joint. With this as a goal, processes of welding were tested.

1. Argon-arc welding with independent arc and layer of flux, using welding wire.

2. Argon-arc welding with a layer of flux and tungsten electrode, with welding plate, laid with rib end to end.

3. Argon-arc welding with a layer of flux and tungsten electrode with gap on remaining aluminum lining, with application of welding wire.

The presence of very large quantity of pores in obtained welded joints, unsatisfactory alloying of basic material with welding metal (Figure 2), and also complexity of suggested processes forced us to give up further work in this direction

and to be occupied with the search for the possibility of obtaining SAP, which without losing substantially its properties, would possess the ability to be welded by fusion.

Unstable burning of arc and unique melting of basic material under conditions of arc welding are, in our opinion, connected with the unfavorable, from the point of view of welding, distribution therein of oxides and presence of sources of gases (hydroxide $Al_2O_3 \cdot 3H_2O$ and fats).

At present, there is no single opinion about the nature of the distribution of the oxidized phase in SAP material.

A majority of researchers affirm that SAP constitutes an aluminum matrix with oxidized inclusions evenly distributed in it [3-5].

A number of foreign authors consider that SAP can be considered as a very fine-grained material with dispersed particles of aluminum oxide on boundaries of grains [6].

In our opinion, expressed points of view, especially first, about the structure of SAP are not sufficiently founded.

On the basis of data obtained in a number of domestic and foreign works [7, 8] on the study of the properties of SAP and oxide phase present in it, it is possible to assume that oxide film, being around particles of aluminum, is very thin and plastic, is incompletely destroyed and is kept on a significant part of their surface even after pressing and rolling of strips to sheet. Considering this, in our work we started on the assumption that SAP consists of deformed, very small particles of aluminum, surrounded by partially destroyed oxide films, forming a unique, three-dimensional network skeleton*.

The point of view about the structure of SAP expressed by us agrees well with its properties and behavior during welding.

Actually, in the process of arc welding, under the action of cathode sputtering of arc and molten flux**, there occurs destruction and washing-out of the surface and internal oxide films. Besides, due to limited activity of flux, its action at some depth is exhausted, and it is not in a state to advance further the front of melting.

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*The hypothesis of the frame structure of SAP, expressed by us recently, found confirmation in a number of foreign works [9, 10].

**We have in mind arc welding with a layer of flux.

The remaining internal oxide film forms on the surface of the pool a practically continuous oxide film which prevents joining of liquid metal with basic, unfused metal (Figure 3).

Under action of pressure of the arc, liquid metal is ejected onto unfused edges of welded plates and is crystallized in the form of drops and incrustations affected by pores. The appearance of pores in crystallized drops and incrustations is the result of unfavorable action of gases, forming during welding as a result of decomposition of fats and water of crystallization in material. Gases which separate during heating of SAP evoke additional oxidation of metal in zone of the arc and promote appearance of porosity in near-seam zone.

To obtain SAP possessing the ability to be welded by the method of fusion, it is obviously necessary to crush the internal oxide films and to remove remainders of fats and moisture.

Numerous experiments and investigations showed that redistribution of oxides and removal of sources of gases can be attained by carrying out additional annealing of blanks (pressed strips or briquettes) at a temperature of 650 -- 700° C with their subsequent deformation.

In the process of annealing at these temperatures, in the material, besides its degassing, there apparently occur the following phenomena:

1. Thickening of internal oxide films as a result of the reaction of aluminum with water of crystallization:

$$2\,Al + 3\,H_2O \longrightarrow Al_2O_3 + 3H_2.$$

2. Transition of amorphous oxide of aluminum into less plastic modification γ-Al_2O_3.

3. Cracking of oxide films due to significant difference in the coefficient of thermal expansion of aluminum and its oxide and due to transition of oxide into other modification.

All these processes prepare the conditions for splitting of oxide films during subsequent deformation.

On the basis of this work a technology was developed for the manufacture of welded SAP, differing from the usual one in

that the briquettes are subjected to annealing at a temperature of 650 -- 680° C in vacuum with their subsequent deformation*.

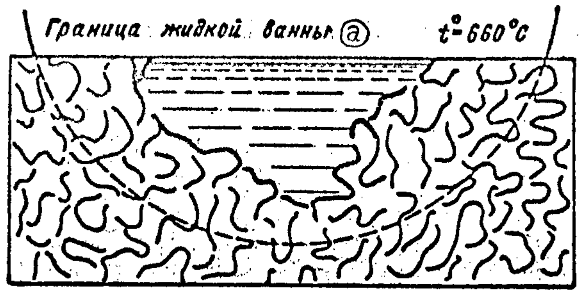

Figure 3. Diagram of fusion of usual SAP during arc welding with application of flux.

a -- Boundary of liquid bath.

Welded SAP, while practically preserving strength characteristics of usual SAP, possesses the following properties:

1) Welds well by fusion as well as with application of flux, so also without it;

2) Does not distend during heating to 900° C inclusively (sheets of usual SAP distend during brief heating to a temperature higher than 500 -- 550° C);

3) Has higher plasticity (Table 1).

Resulting (welded) SAP can be welded by arc welding with application of fluxes, so also in a medium of argon. However, the latter method is more desirable in production, inasmuch as in this case there is no necessity for subsequent washing of welded joints from remainders of fluxes.

Investigations showed that for full melting of sheets of welded SAP during argon-arc welding end to end, it is necessary to apply significantly larger welding current than during butt welding of sheets of the same thickness from aluminum and its alloys.

Thus, during welding of SAP sheets of 1.5-mm thickness, full melting was observed only for currents 300 -- 320*a* with

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*Patent No 141308, 1960.

speed of welding 18 m/hr. The process of welding is stable, with good penetration; however, run of welded seam is somewhat wide. This circumstance is connected with the fact that during welding of SAP with large currents ensuring penetration, a wide heating-up zone will form, in which the surface of basic material is melted down and a puddle of liquid metal, formed basically from welding wire, spreads on this surface.

Table 1

Mechanical Properties of Usual and Weldable SAP at Room and High Temperatures (6.9 % Al_2O_3)

(a) Температура испытания в °C	(b) Предел прочности в кг/мм²		(e) Предел текучести в кг/мм²		(f) Угол загиба в град	
	(c) Обычный САП	(d) Свариваемый САП	Обычный САП	Свариваемый САП	Обычный САП	Свариваемый САП
20	31—37	30—36	20—25	27—31,5	40—50	150—180
500	6—8	4—6,5	4—6	3,5—5	—	—

a -- Temperature of test, in °C; b -- Ultimate strength, in kg/mm²; c -- Usual SAP; d -- Weldable SAP; e -- Yield point, in kg/mm²; f -- Angle of bend, in degrees.

The welding wire is thereby overheated and, while oxidizing on the surface, gets into the puddle as if in a case which sometimes leads to formation on its end of a drop which, under action of pressure of the arc, can be ejected onto edges of welded sheets. A certain improvement in formation of the run of the welded seam was attained by application of welding wire of large diameter.

In connection with the fact that application of large currents during welding of SAP end to end hampers good formation of runs, it was decided to conduct the process of welding with comparatively small currents, but with application of V-shaped dressing of edges of welded sheets or with a gap between them.

As shown by experiments, V-shaped dressing of edges contributes little to a drop in welding current ensuring penetration.

A quality, welded joint with satisfactory formation of runs with currents close to those usually applied, was obtained during welding of sheets with a gap with the simultaneous application of V-shaped dressing of edges (Figure 4); besides, an important factor affecting penetration was a correct feed of welding wire.

During welding of usual aluminum alloys, welding wire should be introduced directly into puddle; besides, its end should at all times touch puddle. Such a method of feeding welding wire during welding of SAP sheets end to end with a gap is unacceptable due to difficulty of melting it. Actually, if one is to continuously pass wire directly into puddle, then, while being melted, it will fill the gap and spread until it will be subjected to the influence of welding arc, i.e., until edge of welded sheets are melted down. Subsequently, in connection with the presence of layer of molten welding metal, fusion of edges of sheets, and especially their face and reverse sides, is hampered.

During welding of SAP, welding wire should be passed so that it enters bath in separate portions. This is possible to attain by intermittent feed of the welding wire itself or feeding it onto the electrode (Figure 5).

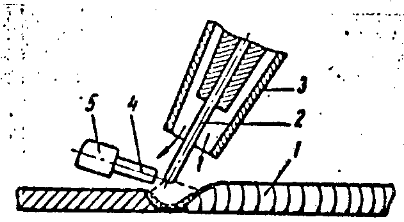

Figure 5. Diagram of automatic argon-arc welding of SAP, end to end, with a gap, with welding wire: 1 -- seam; 2 -- tungsten electrode; 3 -- nozzle; 4 -- welding wire; 5 -- mouthpiece.

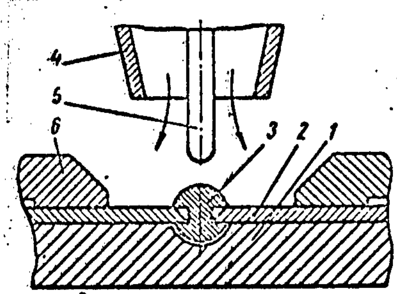

Figure 6. Diagram of welding of SAP, end to end, with a gap, with application of milled wire: 1 -- lining; 2 -- welded plates; 3 -- milled wire; 4 -- nozzle; 5 -- electrode; 6 -- clamps.

In the latter case, wire is fused and, consequently, also enters puddle in separate drops. During the time of formation of drop, the arc succeeds in moving forward and sufficiently heats up and fuses the edge of sheets which are free from liquid addition metal.

Due to shrinkage of molten metal during its crystallization during welding of SAP sheets, end to end, with a gap, there is observed a decrease of the gap toward the end of the seam.

It is possible to avoid this deficiency by means of assembly of sheets with an increased gap, tack welding and bilateral welding with milled wire embodied in joint of welded plates (Figure 6).

As shown by experiments, welding of thin sheets of SAP up to 1.0 mm thick is expedient without a gap of the non-melting electrode. Welding of sheets 1.5 mm thick and larger is possible with a gap, so also without it; moreover, in the case of welding with a gap, one should weld with a non-melting electrode, but in the case of welding without a gap -- melting electrode.

In Table 2 are given mechanical properties of welded joints obtained during argon-arc welding of SAP sheets end to end.

Table 2

Mechanical Properties of Welded Joints without Reinforcement Obtained during Automatic Argon-Arc Welding of SAP Sheets End to End, with Application of Welding Wire of AMg6 Alloy

a Содержание Al_2O_3 в %	b Тип соединения	c Температура испытаний в °C	d Предел прочности в $кг/мм^2$	e Относительная прочность в %	f Угол загиба в град	g Примечание	
6,8	h Без зазора	20	24,0—27,7 25,5	81	—	Сварка поперек прокатки k	
	Без зазора с разделкой i кромок	20	23,6—25,9 24,6	85	—	Сварка вдоль прокатки l	
	j С зазором	20	30,5—32,5 31,2	87	—	k Сварка поперек прокатки	
		500	6,0—6,5 6,3	96	—		
		20	31,2—31,5 31,4	93	—	l Сварка вдоль прокатки	m Отжиг брикетов в вакууме
			35,1—35,3 35,1	100	76—97 82	k Сварка поперек прокатки	
10,6	Без зазора с разделкой i кромок		32,1—33,1 32,5	84		Сварка вдоль прокатки l	

a -- Content of Al_2O_3, in %; b -- Type of joint; c -- Temperature of tests, in °C; d -- Ultimate strength, in kg/mm^2; e -- Relative strength, in %; f -- Angle of bend, in degrees; g -- Note; h -- Without gap; i -- Without gap, with dressing of edges; j -- With gap; k -- Welding across rolling; l -- Welding along rolling; m -- Annealing of briquettes in vacuum.

Judging from obtained results, relative strength of welded joints, obtained during automatic argon-arc welding of sheets of weldable SAP, constitutes at a temperature of 20° C 81 -- 100 percent and at a temperature of 500° C -- 96 percent; besides, best results are obtained during butt welding with a gap of desired SAP. Destruction of welded joints during test for break, as a rule, occurs on near-seam zone; sometimes, samples break on basic material.

It is interesting to note that prolonged holding of welded joints at 400 -- 500° C does not change ultimate strength at room temperature.

Welded joints obtained during argon-arc welding of SAP with welding wire of AMg6 alloy possess good plasticity (angle of bend 76 -- 97°) and airtightness.

As shown by investigations, in the process of argon-arc welding of SAP there occurs an insignificant melting of basic material in zone of arc which, obviously, is connected with its characteristic peculiarities (absence of point of fusion, ability to preserve its form during heating to 1000° C and higher, etc.) and with small time of interaction of basic material with liquid welding metal.

In joint obtained during welding by fusion of SAP, it is, in our opinion, possible to separate the following basic sections (Figure 7):

1. Metal of seam.

2. Zone of mutual crystallization of basic and welding metals (Figure 8).

3. Basic material, heated to a temperature which is higher than temperature of fusion of aluminum.

4. Zone of mutual crystallization of basic material (practically coincides with boundary of run of welded seam).

5. Basic material, heated to a temperature which is lower than temperature of fusion of aluminum.

The last three sections, in totality, constitute the near-seam zone of welded joint.

Data of metallographic analysis and mechanical tests of joint obtained during welding of SAP show that metal of seam constitutes the welding metal with basic material partially dissolved therein, being mixed and being dissolved in welding material, transfers to it its finely-dispersed oxides of aluminum. These oxides strengthen and decrease the mobility of boundaries of grains of metal of seam, which gives the welded joint high heat strength at temperatures up to 500° C, not peculiar to heat strength of aluminum alloys applied as welding metal.

In connection with this, it is interesting to note that strength of welded joints obtained during welding of SAP at 500° C practically does not differ from composition of welding metal with an aluminum base. Apparently, oxides of aluminum, passing over into metal of seam, exert on it modifying action.

In the process of work on welding of SAP, it was established that weldable SAP welds well with other aluminum alloys; the latter expands possibility of its application for the production of different constructions.

On the basis of conducted work, temporary technological recommendations on argon-arc welding of sheet and pressed weldable SAP were issued.

CONCLUSIONS

1. Causes of unsatisfactory behavior of SAP under conditions of arc welding are established and technology is developed for manufacture of SAP possessing the ability to be welded by methods of fusion welding and having higher plasticity.

2. Weldable SAP can be joined by arc welding with the application of fluxes and a medium of protective gases.

3. Strength of welded joints obtained during automatic argon-arc welding of weldable SAP, with application of welding wire of AMg6 alloy at room temperature, constitutes 81 -- 100 percent of strength of basic material and at 500° C -- 96 percent.

4. Weldable SAP welds well with other aluminum alloys.

End

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PHOTO CAPTION APPENDIX

Figure 1. Appearance of "seam" obtained during argon-arc welding of SAP-1 with a layer of flux.

Figure 2. Macrosection of welded joint obtained in argon-arc welding of SAP-1 with a layer of flux and tungsten electrode, with application of remaining aluminum lining.

Figure 4. Welded joint obtained during automatic argon-arc welding of sheets of weldable SAP end to end with a gap: a -- appearance; b -- view from reverse side of seam.

Figure 7. Macrostructure of welded joint obtained during argon-arc welding of weldable SAP, end to end, with a gap.

Figure 8. Zone of mutual crystallization of welded joint obtained during argon-arc welding of weldable SAP X 270.

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